Passage I

Mitochondria are organelles found in eukaryotic cells. Their primary function is to produce the chemical compound Adenosine Triphosphate (ATP), which is the "energy currency" of the cell. There are several reaction pathways that mitochondria use to generate ATP. The first two steps—anaerobic glycolysis, and the oxidative citric acid cycle—are outlined in Figure 1.

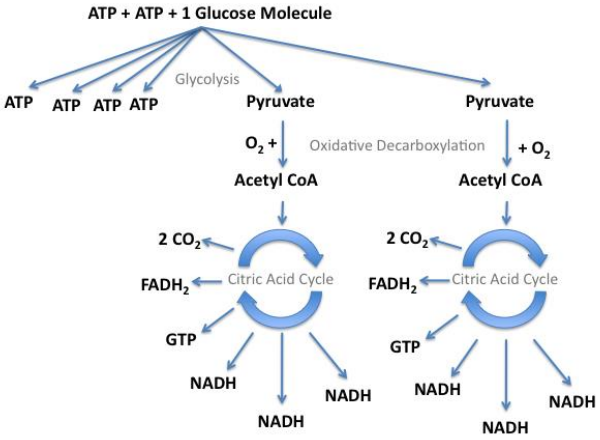


Figure 1

Mitochondrial production of ATP involves the input of oxygen, and the excretion of carbon dioxide. For this reason the oxidative functions of mitochondria are sometimes called "aerobic respiration". The final steps in aerobic respiration involve the other byproducts of the citric acid cycle. GTP is immediately converted into ATP. Meanwhile, NADH and $FADH_2$ both dissociate to form NAD^+ and H, and FAD and 2 H, respectively. Hydrogen then ionizes to produce H^+ and an electron. These free electrons are passed through a series of successively lower energy redox reactions in a process called "the electron transport chain". The electron transport chain is represented in Figure 2. Gibbs Free Energy quantifies a system's chemical potential energy—that is, *a lower energy state* indicates *greater chemical stability*. An *oxidation-reduction potential* is a measure of a compound's likelihood to become reduced by receipt of free electrons. The more negative the value of the oxidation-reduction potential, the more likely it is to generate negative ions, and the more positive the value of the oxidation-reduction potential, the more likely it is to generate positive ions.

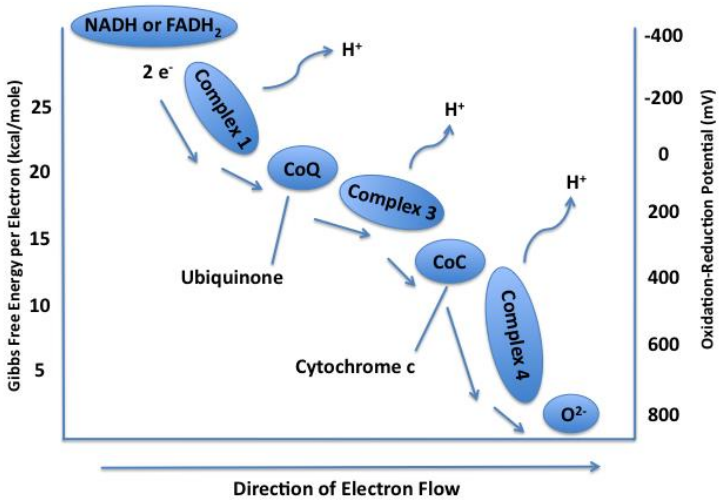


Figure 2

The energy released throughout the redox reactions of the electron transport chain is harnessed to create an H^+ concentration gradient across the inner mitochondrial membrane, which, in turn, drives the final mitochondrial process by which ATP is produced. This process is outlined in Figure 3.

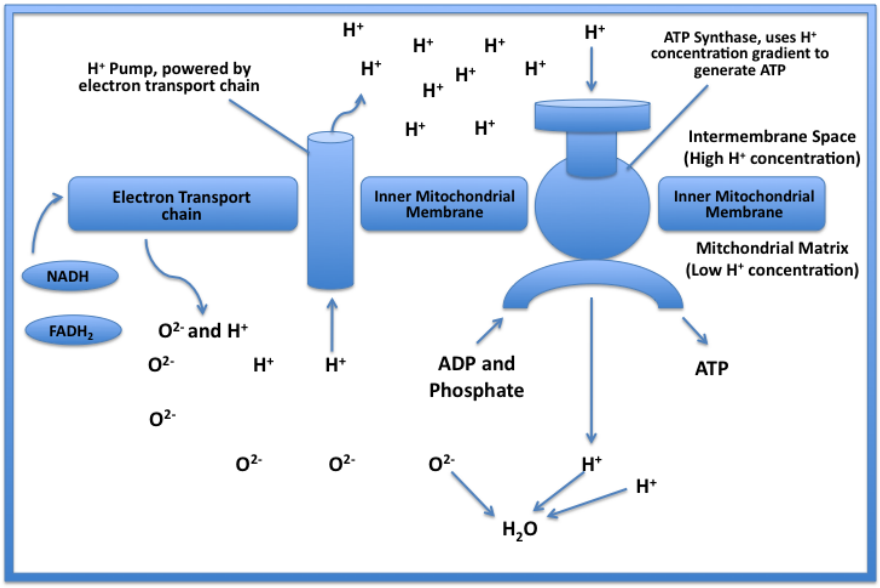


Figure 3

1. Stable compounds are those that are unlikely to denature, i.e. unfold, through reactions. According to Figure 2, which of the following compounds would have the greatest stability?

A. NADH
B. CoQ
C. CoC
D. O^{2-}

2. Using the information in Figure 2, approximately how many Kcal/Mol are generated as NADH is transformed in Complex 1?

F. -200
G. 200
H. 5
J. 20

3. According to Figure 1, which of the following reactions were anaerobic?

A. Glycolysis and Oxidative Decarboxylation
B. Oxidative Decarboxylation and Citric Acid Cycle
C. Citric Acid Cycle and Glycolysis
D. Glycolysis only.

4. Le Chatelier's Principle is stated as follows: "*If a chemical system at equilibrium experiences a change in concentration, temperature, volume, or partial pressure, then the equilibrium shifts to counteract the imposed change and a new equilibrium is established*.
The movement of which of the following molecules in Figure 3 most clearly illustrates Le Chatelier's Principle?

F. H
G. O^2
H. ATP
J. Phosphate

5. A compound X has an oxidation-reduction potential of 1000 mV. Compared to the compounds in Figure 2, compound X is most likely to generate more:

A. negative ions
B. positive ions
C. both positive and negative ions
D. cannot be determined with the given information.

Passage II

In 2002, a group of researchers studied a set of 33 transgenic proteins (proteins created in food crops as a result of genetic modification) in order to compare their properties with those of known allergenic proteins.

Experiment 1

The scientists determined which transgenic proteins are degraded by the digestive system prior to their absorption into the bloodstream. Generally, it was hypothesized that only intact proteins were likely to precipitate an allergic reaction, and that known, wild-type allergenic proteins were resistant to digestion. The scientists subjected both allergenic and transgenic proteins to simulated gastric fluid (SGF) and simulated intestinal fluid (SIF). Their findings are summarized in Table 1.

Table 1

Protein Type	Protein Function	Degraded in SGF	Degraded in SIF
Transgenic	Bt Toxin (Transgenic Proteins 1-11)	No	No
	Glyphosphate Tolerance (Transgenic Proteins 12-22)	Yes	No
	Marker (Proteins 13-33)	Yes	Yes
Allergenic	Peanut Allergen	No	No
	Pollen Allergen	Yes	Yes
	Wheat Allergen	No	No

Experiment 2

The scientists then decided to study the primary structure—that is, the amino acid sequence—of the same 33 transgenic proteins, and search for sequences of at least six amino acids that were identical to those of any known allergen. Such short, linear sequences are called “epitopes”, and are thought to act as functional subunits within a protein. Their findings are summarized in Table 2.

Table 2

Allergenic Protein Type	Percent of transgenic proteins containing 6-amino acid epitopes homologous to allergenic epitopes		
	Peanut Allergen	Pollen Allergen	Wheat Allergen
Bt Toxin (1-11)	93%	12%	28%
Glyphosphate Tolerance (12-22)	22%	54%	79%
Marker (13-33)	0%	35%	68%

Despite the scientists' findings in Experiment 2, due to the limited amount of information available in 2002 on allergenic proteins themselves, it was impossible to determine whether or not the homologous epitopes shared by allergenic and transgenic proteins were potential binding sites for IgE (which is the substance responsible for initiating the body's allergic reaction), and thus, an indication of a protein's potential allergenicity.

6. According to Tables 1 and 2, Bt Toxin is most closely correlated with which of the following allergens?

F. Peanut
G. Pollen
H. Wheat
J. Both Peanut and Wheat

7. Based on the information in Tables 1 & 2, which of the following allergens creates the most severe allergic reaction in humans?

A. Peanut
B. Pollen
C. Wheat
D. Cannot be determined with the given information

8. What was the likely purpose of the two sets of experiments?

F. To determine whether genetically-modified foods contributed to allergic reactions
G. To determine whether allergenic substances are successfully digested
H. To determine whether transgenic substances have the same amino acid sequences as allergens
J. To determine the impact that wheat allergen has on pollen and peanut allergens

9. Which of the following protein types in Experiment 1 would be digested in the stomach, but not in the intestine?

A. Glyphosphate Tolerance
B. Bt Toxin
C. Pollen Allergen
D. None of the above proteins

10. What is a possible explanation for the fact that the results for pollen in Experiment 1 contradict that experiment's prediction of what would result in an allergenic substance?

F. The fact that pollen comes from a plant substance, rather than animal substance
G. The fact that pollen is inhaled rather than absorbed through the stomach
H. The fact that it is not successfully degraded in both SGF and SIF
J. The fact that it is an allergenic rather than a transgenic substance

11. A scientist carrying out a version of Experiment 2 found a newly discovered transgenic protein that carried the following partial amino acid sequence, with each letter as an abbreviation of an amino acid:

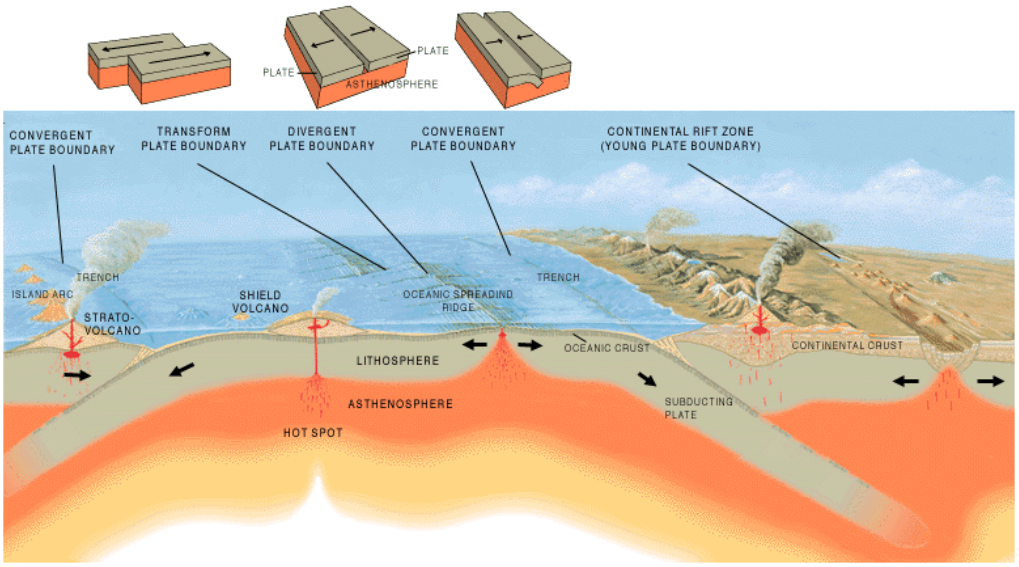
ACQGHIPDNRKC

Which of the following allergen sequences of amino acids would the transgenic protein contain?

A. AQHPNK
B. CQGRKC
C. GHINRK
D. HIPDNR

Passage III

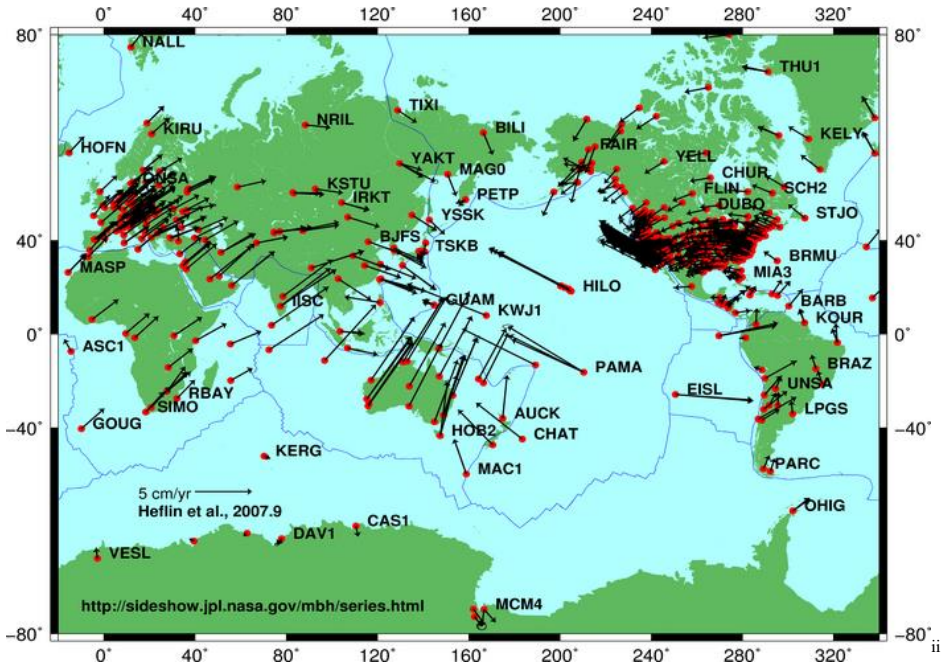
Plate Tectonics is the study of the movement of Earth's large plates throughout Earth's lithosphere, with a focus on prediction of earthquakes and postulating the past and present geography of the planet. Figure 1 depicts the process of tectonic plate shift.



i

Figure 1

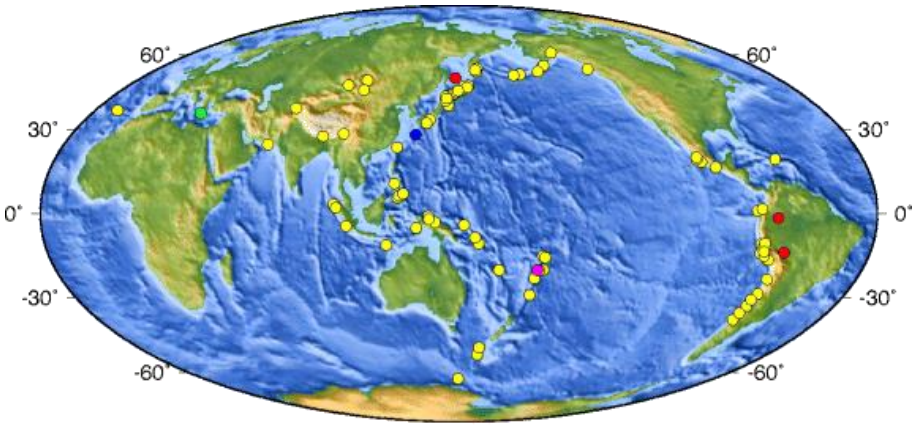
NASA has used its Global-Positioning System of 24 Satellites to record the movements of Continental Plates throughout Earth's Lithosphere. The vectors in Figure 2 below show satellite recordings of the direction and relative speed that continental plates are shifting.



ii

Figure 2

The U.S. Geological Survey has compiled a map of earthquakes of extremely high magnitude – greater than 8.0 on the Richter Scale – that have take place since the year 1900. In Figure 3 below, the small circles each indicate an 8.0 or higher earthquake.



Magnitude 8.0 and Greater Earthquakes Since 1900 [iii]

Figure 3

12. The lines separating continental plates on Figure 2 would most clearly be found in which of the following layers of Earth?

F. Stratosphere
G. Thermosphere
H. Asthenosphere
J. Lithosphere

13. According to Figure 1, which of the following would one most likely find close to a subducting plate?

A. Hot Spot
B. Shield Volcano
C. Stratovolcano
D. None of the Above

14. Using the information in Figure 2 and Figure 3, what is the relationship, if any, between the length of the continental plate vectors and the presence of high magnitude earthquakes?

F. The greater the vector length, the more high magnitude earthquakes.
G. The lower the vector length, the more high magnitude earthquakes.
H. The greater the vector length, the fewer high magnitude earthquakes.
J. There is no relationship between vector length and high magnitude earthquakes.

15. Which of the following represent logical reasons as to why the different projections of the maps were chosen as they were in Figures 2 and 3 to portray data about earthquakes and continental shifts?

I. The fully flattened map projection, in Figure 2, is used because it allows straight-line vectors to be more clearly portrayed.
II. In Figure 3, the scientists thought that showing the actual size of land masses was preferable to showing a flat version, since it would more accurately show how much of an area is impacted by earthquakes.
III. Doing a fully flattened map projection in Figure 3 is not necessary, since small circles can as easily be represented on an accurate-area map as they would be on a fully flattened map.

A. I and III
B. II and III
C. II only
D. I, II and III

16. What is the most probable reason that in Figure 2 there are far more continental plate shifting vectors in Europe and the United States than in other parts of the world?

F. A higher prevalence of earthquakes
G. A higher amount of satellite coverage data
H. A higher prevalence of continental plates
J. A lower amount of heat interference

Passage IV -- Embryonic Cell Differentiation

In the early 1900s, two biologists studied cell differentiation in developing embryos. Both scientists conducted experiments on organisms at the two-cell stage of embryonic development, and both came to different conclusions.

Scientist 1

Scientist 1 studied cell differentiation in the development of sea urchin embryos. Once the embryos reached the two-cell stage of development, he mechanically separated the two blastomeres (embryonic cells) by shaking the tube in which they were contained. Scientist 1 later observed that each cell, despite having been separated, gave rise to a complete, though slightly smaller sea urchin embryo. This led him to believe that each cell retained the complete set of "determinants" (i.e. genes) necessary to develop into the full organism from which that cell was removed. That is—internally—every embryonic cell has an equal potential differentiate. This hypothesis led scientist 1 to conclude that the pathway of embryonic cell differentiation is regulated mainly by factors external to the cell, and on a particular cell's position within the developing embryo.

Scientist 2

Scientist 2 experimented with frog embryos at the two-cell stage of development. By destroying one of the blastomeres with a hot needle and leaving the dead cell body attached to the remaining live blastomere, he observed that—after further mitotic divisions—the organism developed into only half of a complete embryo. This led the scientist to believe that the determinants of developing embryos were portioned out qualitatively at the time of cell division, until each cell possessed only the substances required for its own specialized functions and development. That is, each cell acted as the individual pieces of a mosaic. For this reason, his theory is sometimes described as the "mosaic hypothesis". Ultimately, scientist 2 concluded that the fates of developing embryonic cells are determined by each cell's unique and unequal array of "determinants", and that cell differentiation occurs independently of external conditions, such as the cell's position within the developing embryo.

17. Which of the two scientists used mechanical separation of the cells to conduct his experiment?

A. Scientist 1 only
B. Scientist 2 only
C. Both of the Scientists
D. Neither one of the Scientists

18. On which of the following statements do both Scientists 1 and 2 agree?

F. Each cell of a two-celled embryo contains all of the genetic determinants for a complete organism.
G. A one-celled embryo contains all of the genetic determinants for a complete organism.
H. Genetic determinants for a complete organism are not present in a one-celled embryo.
J. Genetic determinants for a complete organism are not present in each cell of a two-celled embryo.

19. A person has had his arm removed in an accident. What would scientist 2 say about whether the genetic determinants to recreate the arm were present elsewhere in the body?

A. They would be present in person's torso.
B. They would be present in every cell of the person's body.
C. They would be present in the arm that remained on the body.
D. They would not be present elsewhere in the body.

20. With the discovery of DNA in the 20th century, which scientist's theory was eventually proven to be correct?

F. Scientist 1 only
G. Scientist 2 only
H. Neither Scientist 1 nor Scientist 2
J. Biologists have not yet reached a conclusion on this topic

21. An observer makes the following statement about the two scientists:

"The sea urchin is a far more uniformly structured creature than a frog. Removal of one part of a sea urchin does not make the damaged urchin appear to be significantly different from a fully intact sea urchin."

This observer is directing her critique towards which of the scientists?

A. Scientist 1 only
B. Scientist 2 only
C. Both Scientist 1 and Scientist 2
D. Neither Scientist 1 nor Scientist 2

22. Consider the following statement:

"If a scientist were to remove the nucleus of an endothelial cell lining the stomach of an adult frog, and injected it into an embryonic tadpole cell in which the nucleus had previously been destroyed by radiation, the embryo would develop into a complete, healthy tadpole, then frog."

Which scientist(s) would agree with this statement?

F. Scientist 1 only
G. Scientist 2 only
H. Both Scientists 1 and 2
J. Neither Scientist

23. What would be a logical critique of Scientist 2 by Scientist 1?

A. No simulation of what happens with the two-cell stage of development was conducted.
B. A one-celled organism was used, which would not simulate multi-cellular organism development
C. Since the dead cell was left attached to the living cell, differentiation was hindered
D. Cell differentiation occurs independently of external conditions

Passage V

A physics student wanted to find out why a piano and a flute have distinctly different sounds or "timbres" even when they're both playing the same note. The student knows that a musical note corresponds to a particular pitch, and that pitch is related to the fundamental or natural frequency of a sound wave. Also, the *intensity* of a sound is measured by taking the power of the sound and dividing by the unit area it encounters, expressing the intensity in Watts per Meter squared.

Experiment 1

Using a microphone attached to a computer, the student recorded the sound emitted by a piano upon striking the note E4. The computer analyzed and displayed the frequencies of the various sound waves that were detected. The student then repeated the procedure using a flute as the source of sound. The student's graphs are shown in Figures 1 and 2. Time is measured in seconds, and Amplitude is measured in W/m².

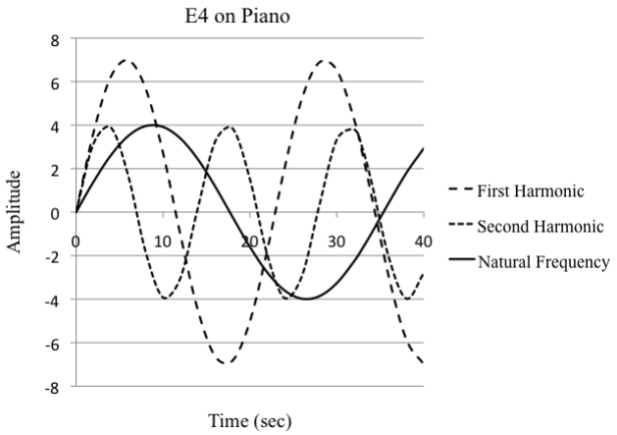


Figure 2

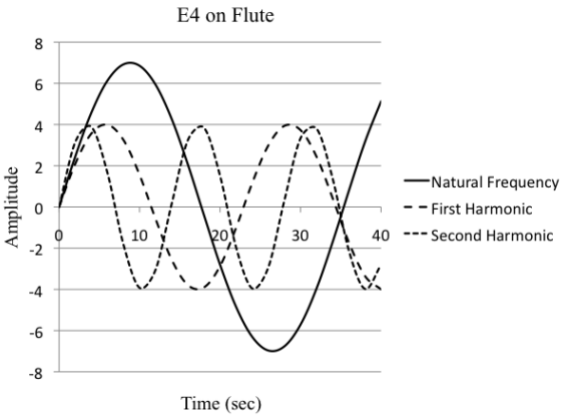


Figure 1

Experiment 2

The student was surprised to discover that a single note from an instrument is composed of not just one frequency of sound wave, but a low, fundamental frequency, as well as several higher frequency sound waves called "harmonics". Using the data collected in Experiment 1, the student created two new graphs to help compare the relative amplitudes of these sound waves. The graphs are shown in Figures 3 and 4.

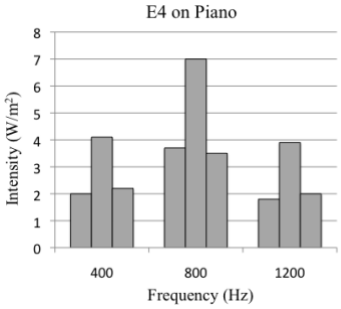


Figure 3

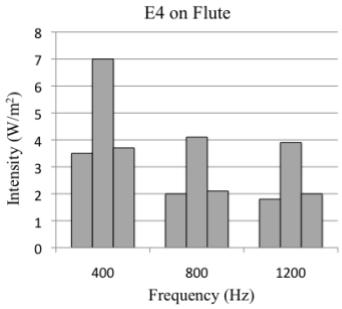


Figure 4

24. To the nearest whole unit, what is the approximate amplitude of a First Harmonic Wave on a Piano at a time of 10 seconds?

F. 4
G. 2
H. 0
J. -4

25. Based on the information in Figure 2 and Figure 4, the sounds wave on the flute with a frequency of 400 Hz is which of the following?

A. Natural Frequency
B. First Harmonic
C. Second Harmonic
D. Identical to the wave at a frequency of 1200 Hz

26. Based on the information in Experiment 1, what characteristic of the sound waves created by an instrument is most responsible for giving it its unique timbre, or sound?

F. The frequency of the waves
G. The amplitude of the waves
H. The time that passes by after the instrument's sound is initiated
J. The particular note that is played

27. Based on the information in Figure 2, which sound wave(s) would provide the greatest sound volume to a listener?

A. Natural Frequency
B. First Harmonic
C. Second Harmonic
D. All three waves will produce an equivalent sound volume

28. Based on the information in Figure 1, after approximately how much time after a piano note was struck would there be a great deal of dissonance, i.e. destructive interference, in the sound?

F. 0.1 seconds
G. 5 seconds
H. 17 seconds
J. 36 seconds

29. Which of the following pairs of powers and unit areas would produce the most intense sound?

A. 300 W, 200 M^2
B. 200 W, 500 M^2
C. 10 W, 5 M^2
D. 500 W, 700 M^2

Passage VI

In ideal populations, the gene pool of a given species is said to be stable. For a population to qualify as ideal, it must meet five criteria:

Population must be large
No immigration or emigration
No mutation
Random mating
Each allele of a given gene has an equal opportunity to reproduce

When these criteria are met, the frequency with which a rare trait occurs does not lessen, and the frequency with which a common trait occurs does not increase. That is, the population is in equilibrium, and the Hardy-Weinberg Equation applies to the genes of that population for which there are two alleles. The Hardy-Weinberg equation states that:

$p^2 + 2pq + q^2 = 1$

where p is the frequency of one allele, and q is the frequency of the other.

Study 1

Over a period of 40 years, a biologist studied the beak size of prairie chickens across four states, and assembled his findings in Table 1. The gene that codes for beak size has two alleles—*B*, which codes for a large beak, and *b*, which codes for a diminutive beak. The biologist also decided to graph the change in each state's population of prairie chickens over time. The graphs are shown in Figures 1 and 2.

Table 1

	1953		1973		1993	
	Population	Phenotype B : b	Population	Phenotype B : b	Population	Phenotype B : b
Kansas	400,000	3 : 1	550,000	3 : 1	600,000	3 : 1
Illinois	25,000	7 : 3	10,000	2 : 1	50	0 : 1
Minnesota	3,000	3 : 2	2,500	3 : 2	3,000	3 : 2
Nebraska	75,000	3 : 1	8,500	3 : 1	200,000	5 : 1

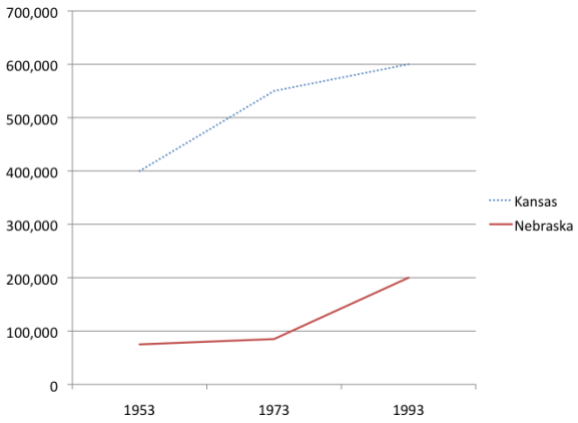


Figure 1

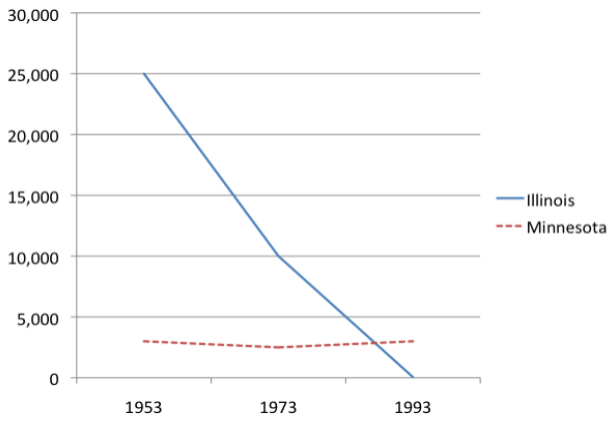


Figure 2

30. In the state of Kansas in 1953, approximately how many prairie chickens will display a large beak?

F. 100,000
G. 200,000
H. 300,000
J. 400,000

31. The phenotype ratio of B to b in the state of Michigan was found to be 9:4. Based on the information in Table 1, it is most likely that the population sample used was:

A. Relatively small
B. Relatively large
C. The population size would likely not have affected the phenotype ratio
D. Cannot be determined from the experiment

32. Assume that in the Harvey-Weinberg equation, p represents dominant traits and q represents recessive traits. Which of the following pairs will have the same phenotype?

F. pp and qq
G. pq and qq
H. qq and qp
J. pq and pp

33. A "genetic bottleneck" occurs when there is a significant drop in population, and a recessive trait becomes dominant. Which of the following situations best demonstrates a genetic bottleneck?

A. Kansas, 1993
B. Illinois, 1993
C. Minnesota, 1953
D. Nebraska, 1953

34. "Genetic drift" occurs when some portion of a population moves to a new environment where one phenotype gives an advantage that was not hitherto experienced in the old environment, causing natural selection. Which of the following situations best illustrates the change to a population that would occur as a result of genetic drift?

F. Kansas, 1993
G. Illinois, 1973
H. Minnesota, 1973
J. Nebraska, 1993

Passage VII

An enzyme is a temperature- and pH-sensitive protein catalyst that significantly increases the rate at which a specific reaction occurs by lowering the reaction's "activation energy". In an enzyme-catalyzed reaction, the reactant is called a "substrate", and one enzyme can only act on one substrate at a time. The activation energy is the minimum amount of energy required in a system for a substance to undergo a given chemical reaction. The activation energies and the net change in Gibbs free energy for a general exothermic reaction both with and without a catalyst are shown in Figure 1.

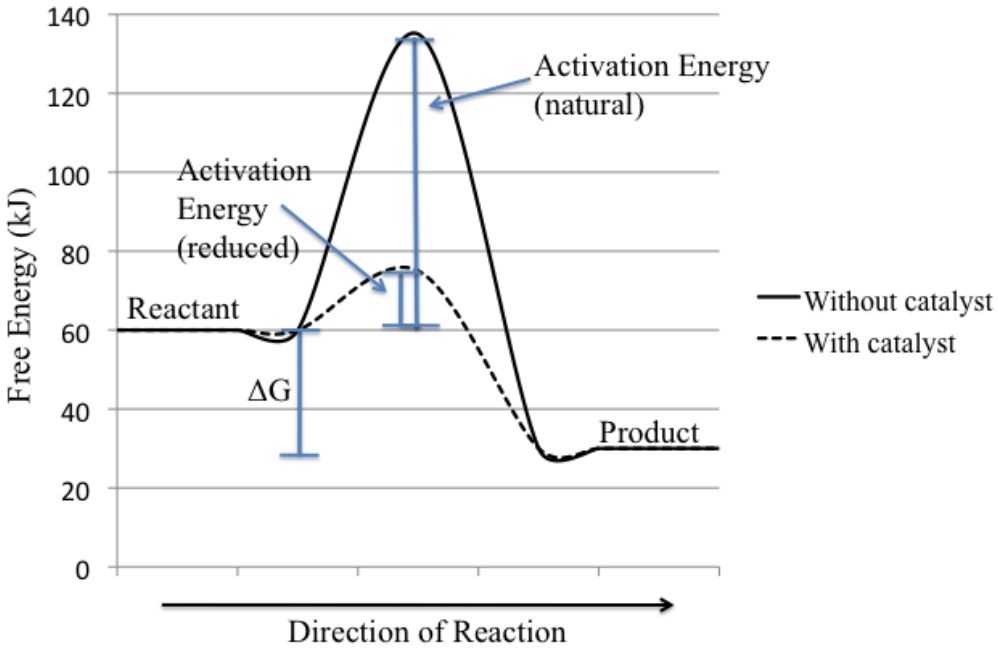


Figure 1

Experiment 1

A microbiology student wanted to study the effect of substrate concentration on the rate of an enzyme-catalyzed reaction in which colorless o-Dianisidine undergoes oxidation to produce a reddish, soluble compound. The student conducted several trials with varying initial concentrations of o-Dianisidine, carefully measured the rate at which the red compound appeared with an infrared absorption spectroscope, and plotted her data in Figure 2. The concentration of peroxidase enzyme (a catalyst) was kept constant throughout her trials.

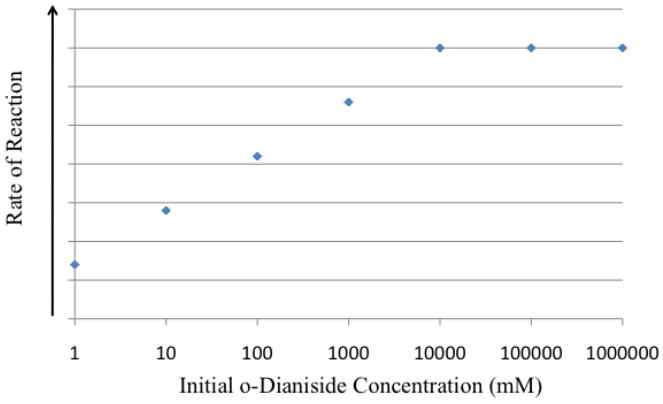


Figure 2

Experiment 2

In a second experiment, the student studied the effect of temperature on the rate of the same enzyme-catalyzed reaction. The student knows that, in general, increasing the temperature of a system will increase the rate of reaction, as applying heat increases the kinetic energy of the system's molecules, thereby enabling more molecules to overcome the activation energy barrier. The student kept constant concentrations of enzyme and initial concentration of substrate throughout all her trials, and conducted the experiment at varying temperatures using a warm water bath. Her results are summarized in Figure 3.

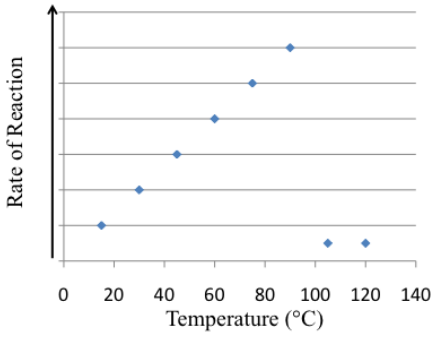


Figure 3

35. Based on the information in Figure 2, at approximately what concentration of o-Dianisidine does the reaction, if plotted linearly, begin to have a slope of zero?

A. 10^3
B. 10^4
C. 10^5
D. 10^6

36. What is the best explanation as to why the rate of reaction in Experiment 2 increases as the temperature increases?

F. The decrease in molecular kinetic energy prevents the molecules from overcoming the activation energy barrier
G. The increase in molecular kinetic energy enables the molecules to overcome the activation energy barrier
H. The increase in molecular kinetic energy prevents the molecules from overcoming the activation energy barrier
J. The decrease in molecular kinetic energy enables the molecules to overcome the activation energy barrier

37. Based on the information in Experiment 1, we can generalize that the relationship between the rate of reaction and the concentration of the substrate is which of the following?

A. Inversely related
B. Equivalent
C. Directly correlated
D. Both inversely and directly related at different points

38. Based on the information in Experiment 1, what is the most likely reason that the rate of the reaction levels off as the substrate concentration increases?

F. Oversaturation of the enzyme
G. Decrease in o-Dianisidine concentration
H. The logarithmic increase in the substrate
J. Overheating of the spectroscope

39. The *equilibrium constant* for a reaction is defined as follows:

The value that expresses how far the reaction proceeds before reaching equilibrium.[iv]

In Experiment 1, when the catalyst is added, how does this affect the equilibrium constant of the reaction compared to the reaction without the catalyst?

A. It increases
B. It decreases
C. It increases then decreases
D. It remains the same

40. In Experiment 2, what is the most likely reason that the rate of reaction drops so drastically after approximately 95˚C?

F. The activation energy barrier, i.e. the amount of energy needed to overcome the reaction, changes
G. The concentrations of enzyme and substrate, i.e. the controls, are modified
H. The enzymes become denatured, i.e. unfolded, after that point
J. The reaction's catalysis, i.e. the rate of the chemical reaction, increases drastically

Key:

1. D	11. D	21. A	31. A
2. H	12. J	22. F	32. J
3. C	13. C	23. C	33. B
4. F	14. F	24. G	34. J
5. B	15. D	25. A	35. B
6. F	16. G	26. G	36. G
7. D	17. A	27. A	37. C
8. F	18. G	28. H	38. F
9. A	19. D	29. C	39. D
10. G	20. F	30. H	40. H

[i] (Illustration by Jose F. Vigil. USGS. [http://pubs.usgs.gov/gip/earthq1/plate.html] {{PD-USGov-Interior-USGS}})

[ii] http://en.wikipedia.org/wiki/File:Global_plate_motion_2008-04-17.jpg

[iii] http://earthquake.usgs.gov/earthquakes/eqarchives/year/mag8/magnitude8_1900_date.php

[iv] http://www.shodor.org/unchem/glossary.html